The Abdus Salam
International Centre for Theoretical Physics

2333-44

Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)

11 April - 1 May, 2012

GNSS Derived TEC Data Calibration

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TEC calibration technique tests

using model simulated data:

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Seminar on Development and Use of the Ionospheric NeQuick Model

Trieste, 30 April-1 May 2012

How accuracy of calibration techniques can be estimated

Examination of residuals after a calibration run

$$Res_{ijt} = S_{ijt} - \Sigma_n c^t{}_n p_n(l_{ijt}, f_{ijt}) \sec \chi_{ijt} - \Omega_{Arc}$$

will provide with useful information about the

Internal consistency of the solution

Residuals are plotted in the following examples for few sample stations.

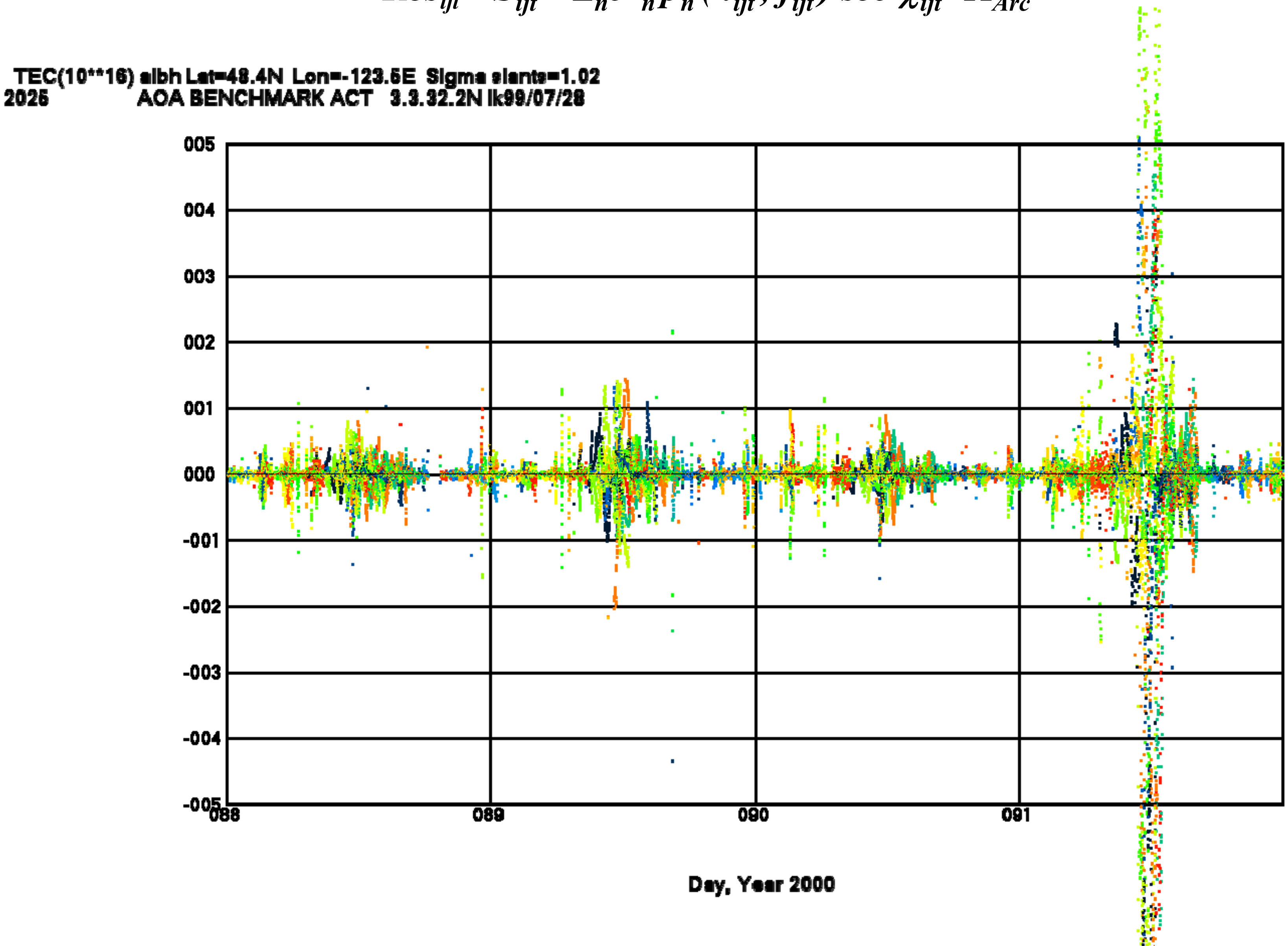
Standard deviation of the individual samples is reported.

Reminder

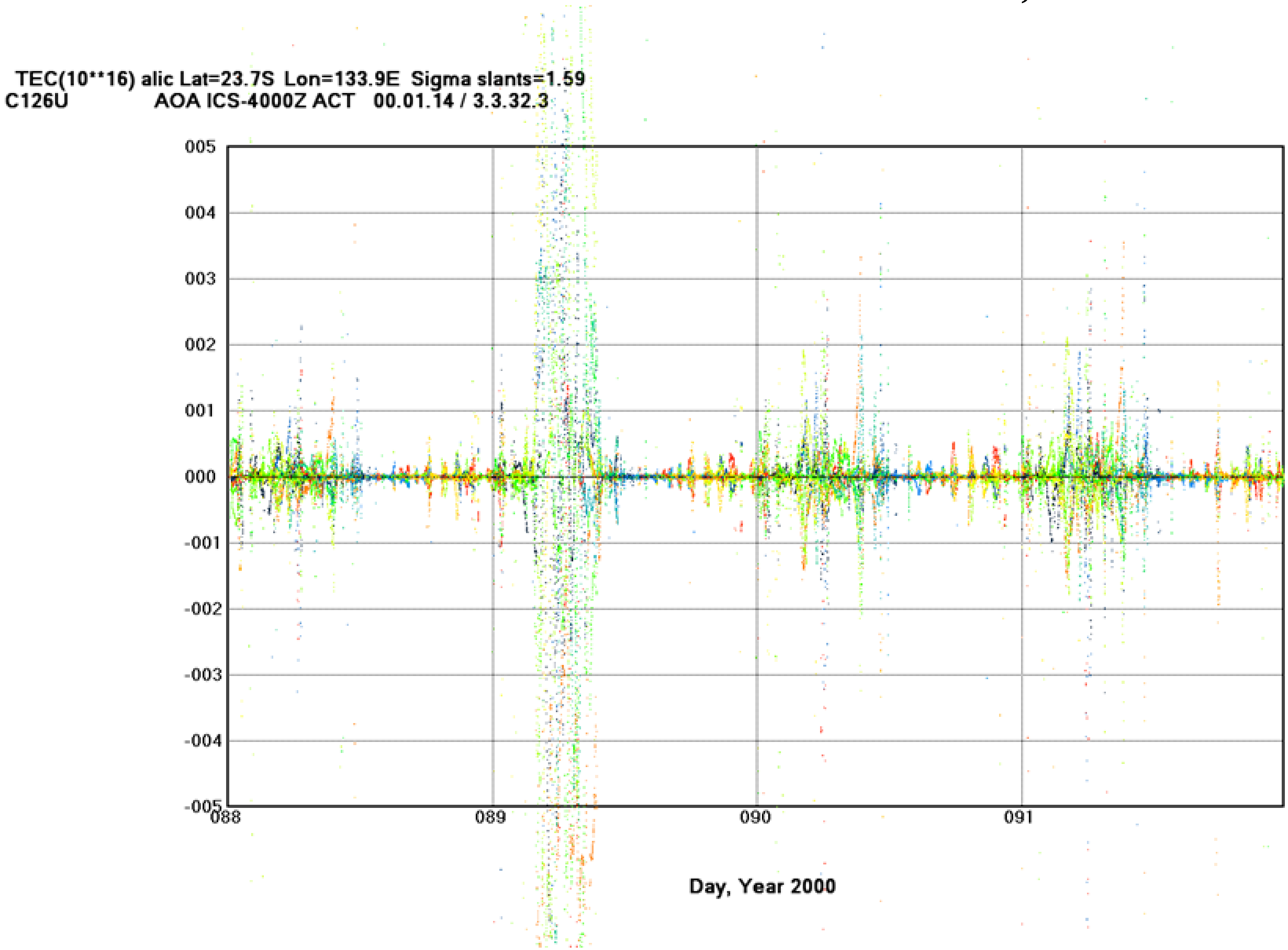
S_{ijt}	the observations
$\Sigma_n c^t{}_n p_n(l_{ijt}, f_{ijt}) \sec \chi_{ijt}$	the expansion of Vertical (Equivalent) TEC
$\sec \chi_{ijt}$	the mapping function
Ω_{Arc}	the unknown arc offset

Internal consistency of the method is estimated from the residuals (actual data)

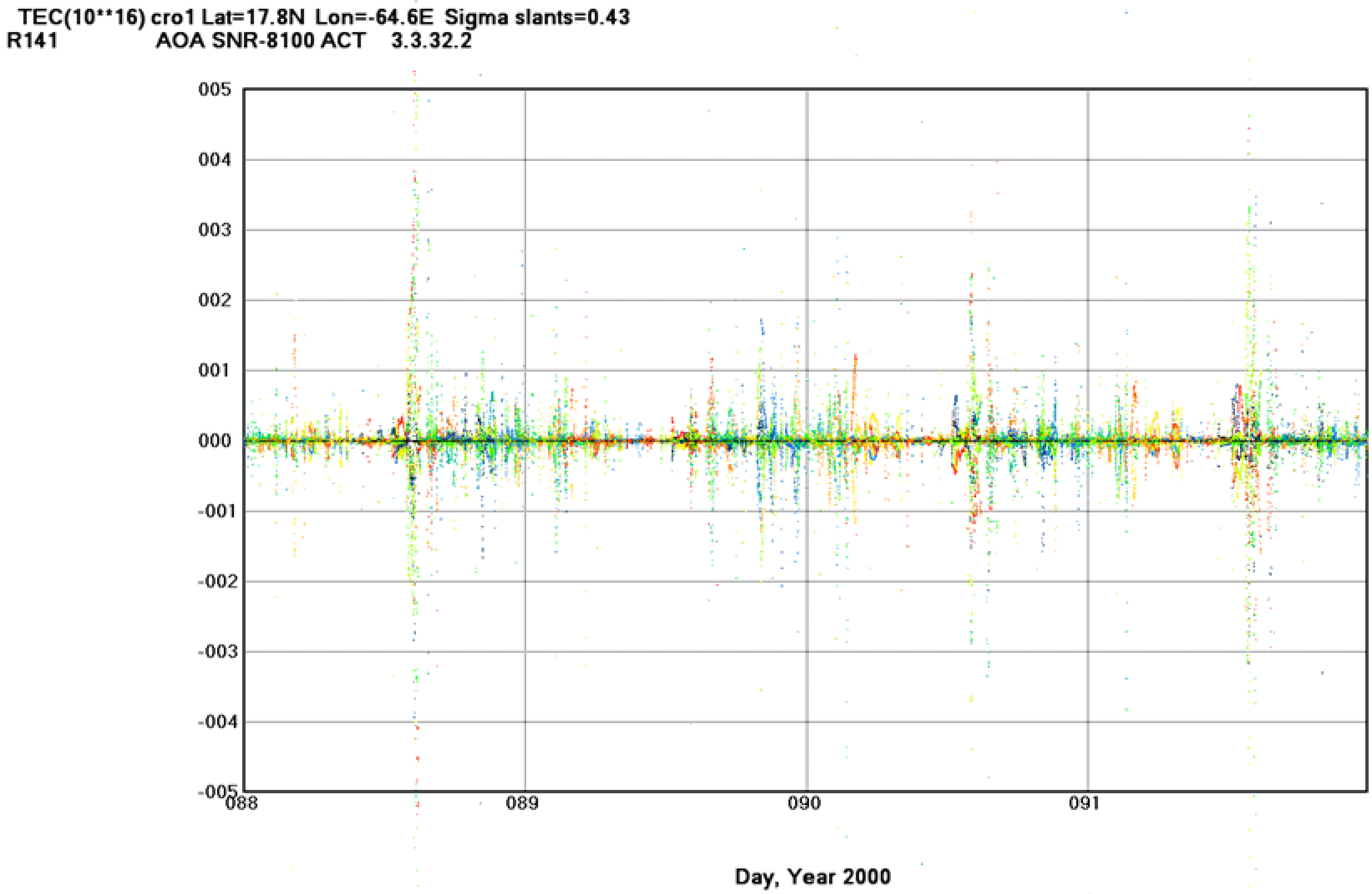
$$Res_{ijt} = S_{ijt} - \Sigma_n c^{t}_{n} p_n (l_{ijt}, f_{ijt}) \sec \chi_{ijt} - \Omega_{Arc}$$



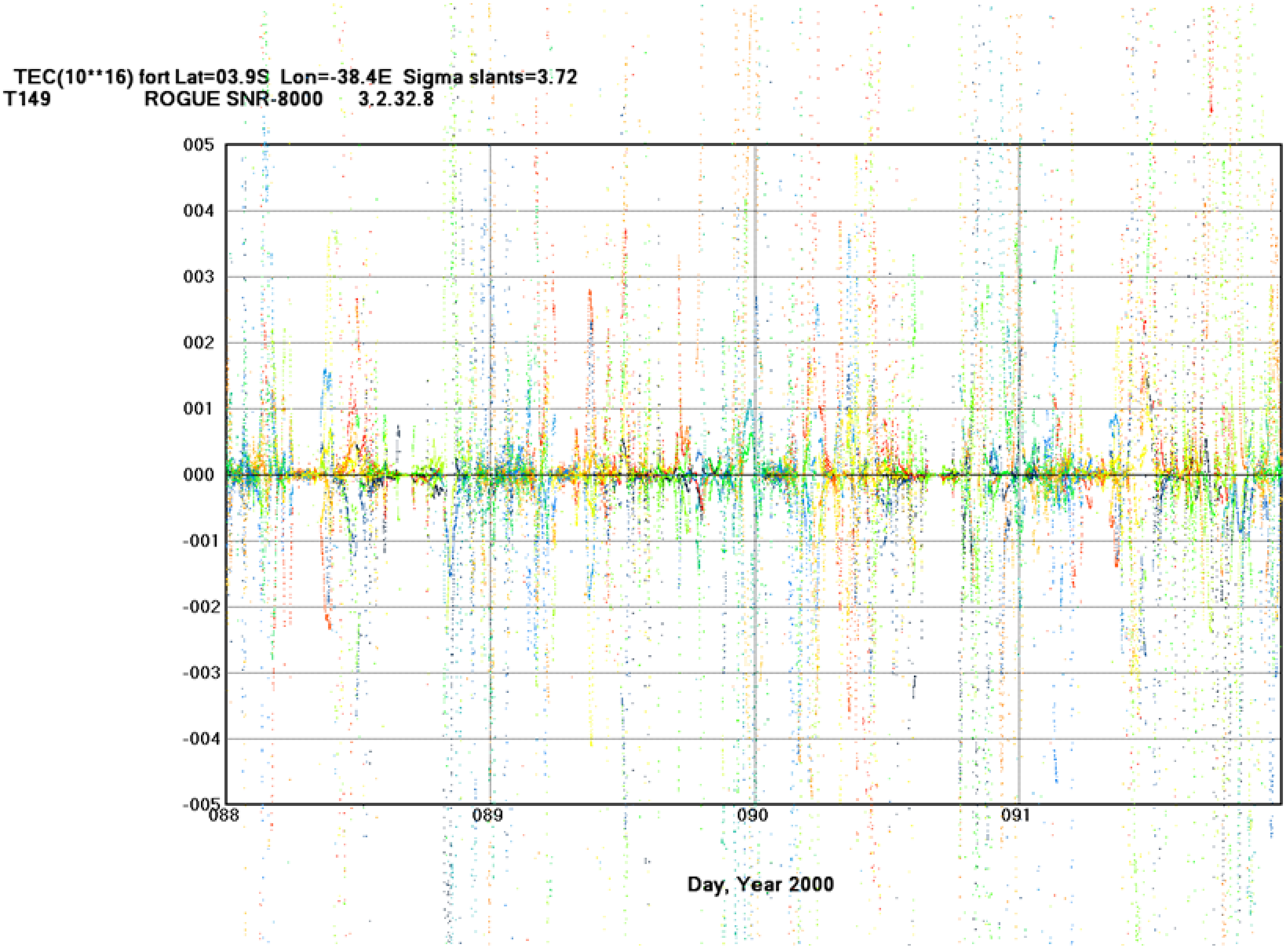
Residuals, actual data



Residuals, actual data



Residuals, actual data



Sigma of the shown sample residuals ranges from ≈ .5 to 4 ***TECu*** according to latitude.

Is this an estimation of the accuracy of the calibration?

No, as this requires a comparison with truth data, which are unavailable

(Incoherent Scatter Radar, Radar Altimeter may help, but are not sufficient).

What can look more like truth data?

Artificial data produced by Ionospheric Models.

But keeping in mind that agreement with artificial data is a condition

necessary but not sufficient to validate the method

The artificial data

Ionospheric models enable to estimate median electron density at some time at some geographic location, i.e. given date and time, latitude, longitude, height.

$$N_e = N_e(t,\phi,\lambda,h)$$

TEC is the integral of electron density along the ray-path from satellite to receiver,

$$TEC = \int N_e(P)ds$$

which will be numerically evaluated as the sum

$$TEC \approx \sum N_e(P_i)\delta s_i$$

or with any more effective numerical algorithm (Gauss, …)

Model TEC computation

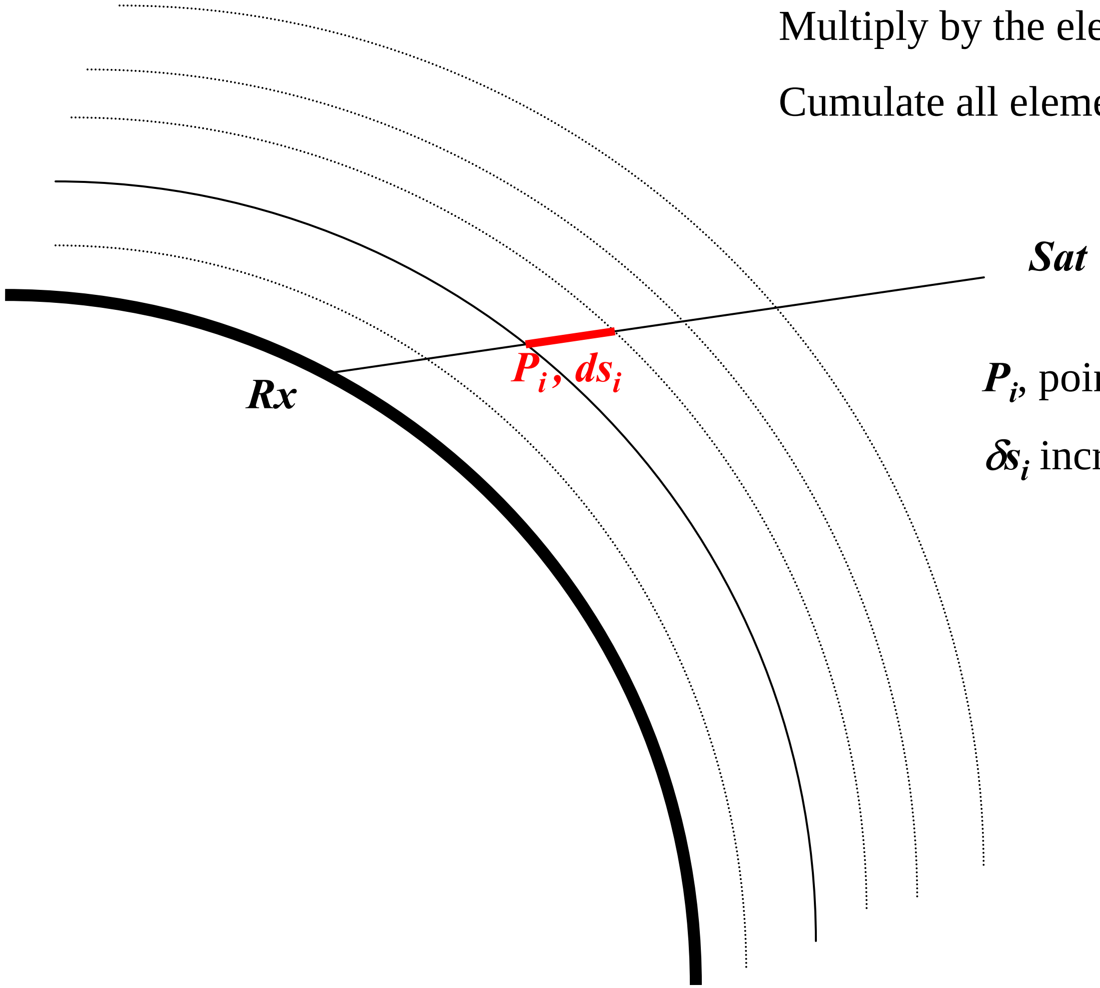
$$TEC = \int N_e(P)ds \approx \sum N_e(P_i)\delta s_i$$

Divide the path in elements δs_i

At each point P_i compute the electron density $N_e(P_i)$ provided by the model

Multiply by the element length δs_i

Cumulate all elements



P_i, point on the generic i^{th} shell

δs_i increment in arc length

Simple uses of artificial data: the mapping function

Which errors do affect the **standard approach** (actual vertical ***TEC***) of mapping function?

Using an artificial ionosphere:

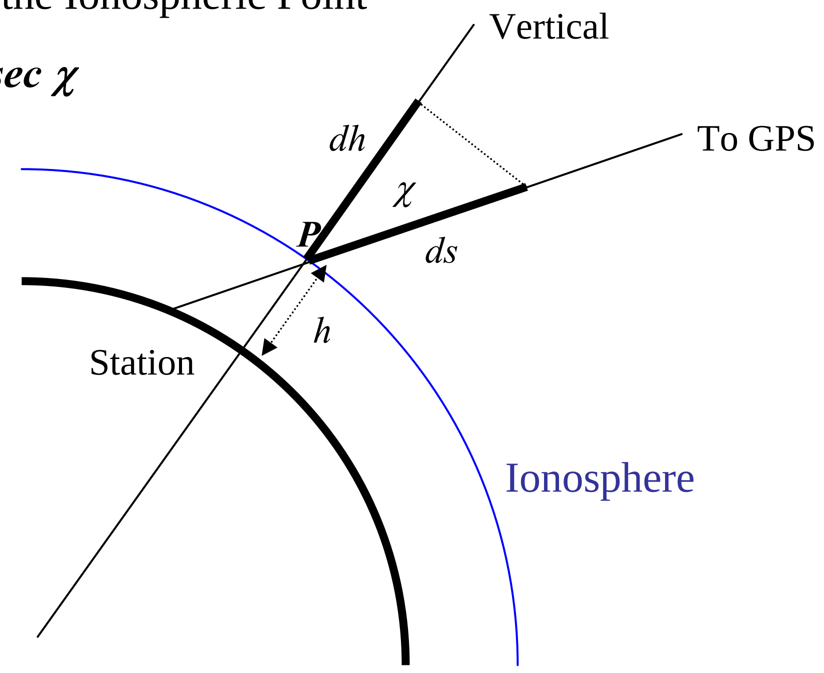
Compute χ

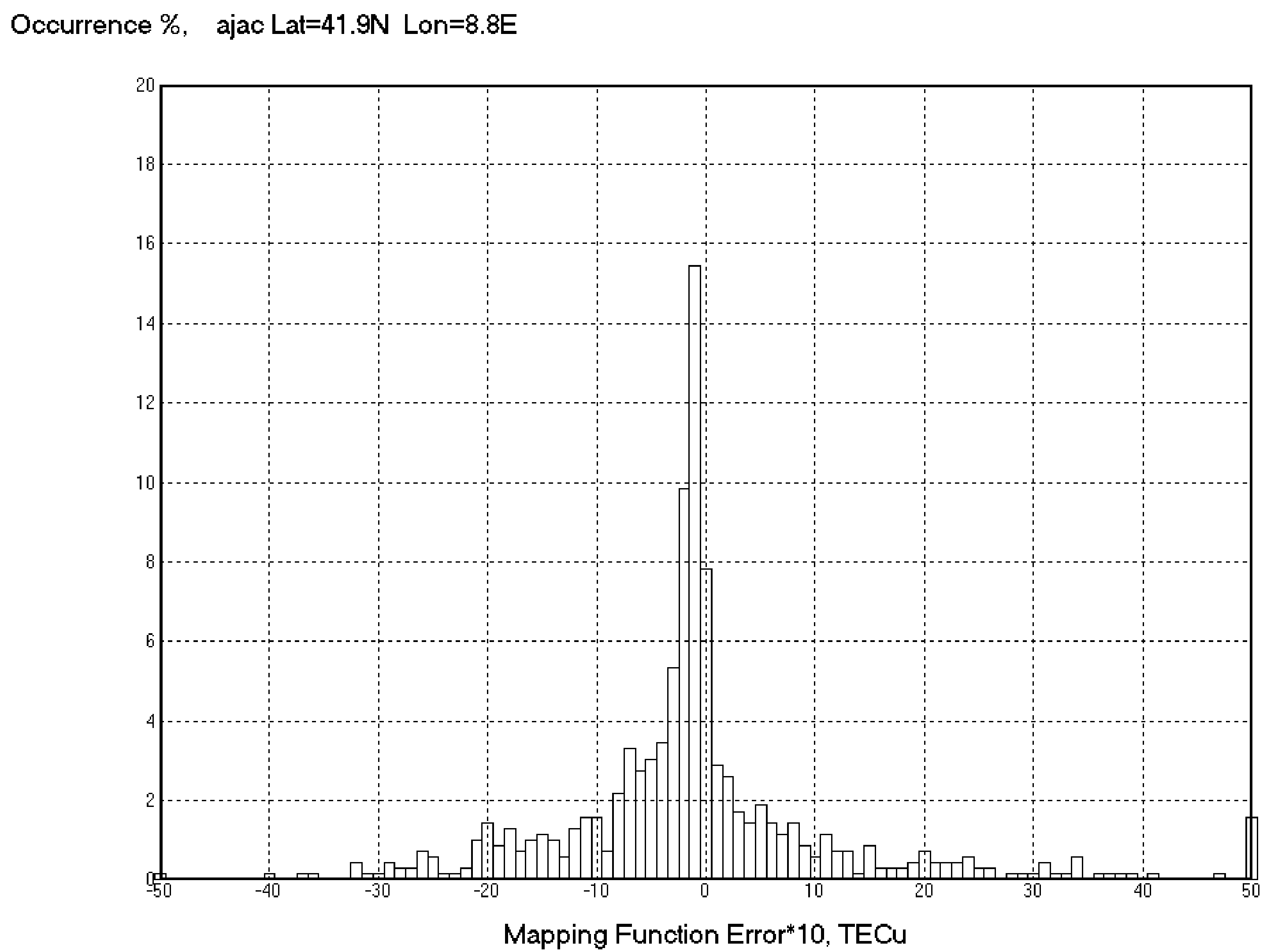
Compute Slant ***S***

Compute Vertical TEC ***V*** at the Ionospheric Point

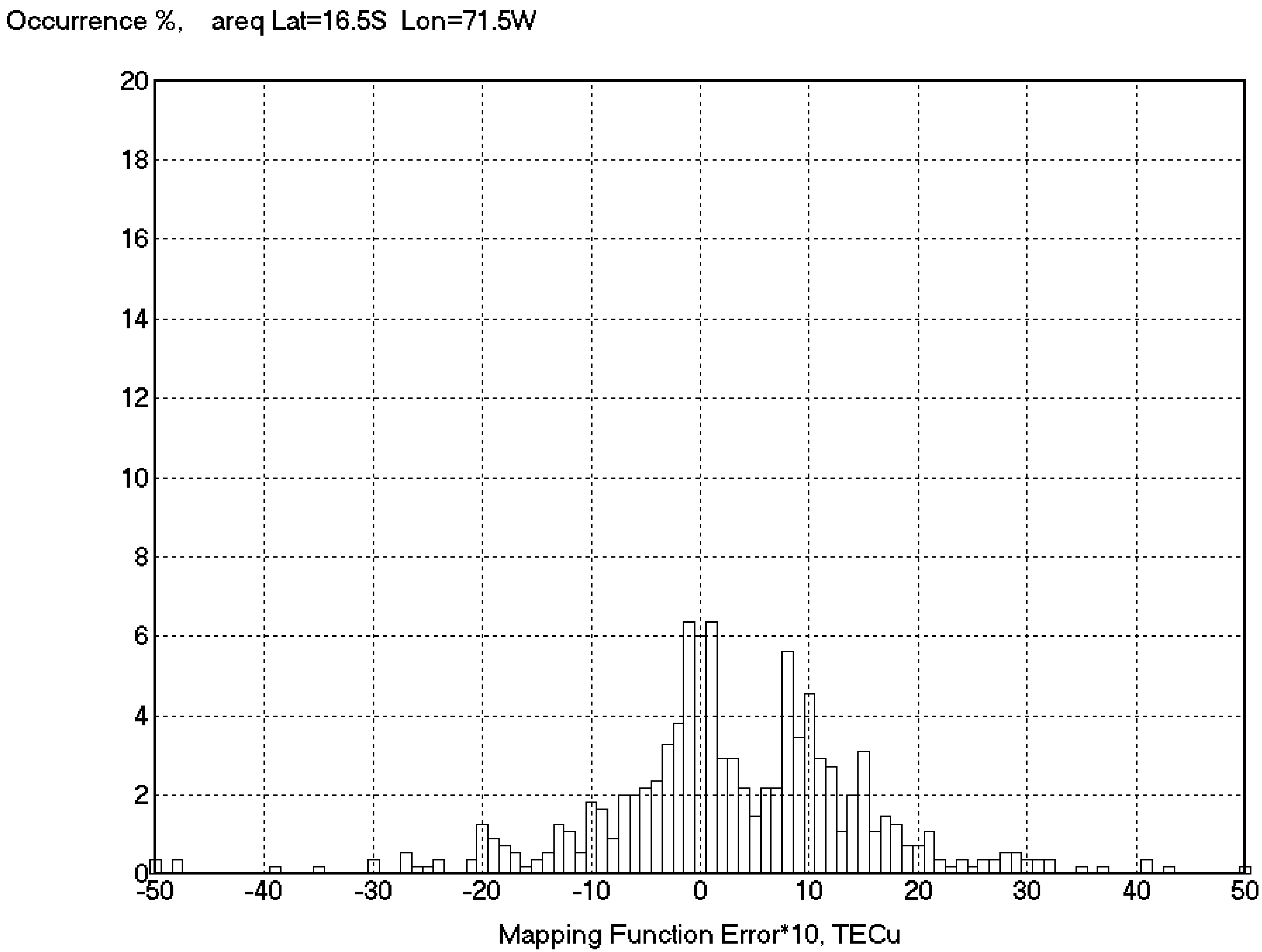
Error: $S - V \sec \chi$

Plot Error distribution





Occurrence %,   ajac Lat=41.9N Lon=8.8E
20
18
16
14
12
10
8
6
4
2
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Mapping Function Error*10, TECu



Occurrence %, areq Lat=16.5S Lon=71.5W
20
18
16
14
12
10
8
6
4
2
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Mapping Function Error*10, TECu

Simple uses of artificial data: ***VEC and VEq***

In the Single-Station / Arc Offset calibration the ***V***ertical ***Eq***uivalent TEC ***VEq*** for which it is exactly $S = VEq \sec \chi$ is used.

How different is ***VEq*** from actual Vertical ***TEC*** (***VEC***) ?

<u>Using an artificial ionosphere</u>:

Compute χ

Compute Slant ***S***

By definition $VEq = S \cos \chi$

Compute Vertical TEC ***V*** at the Ionospheric Point ***VEC***

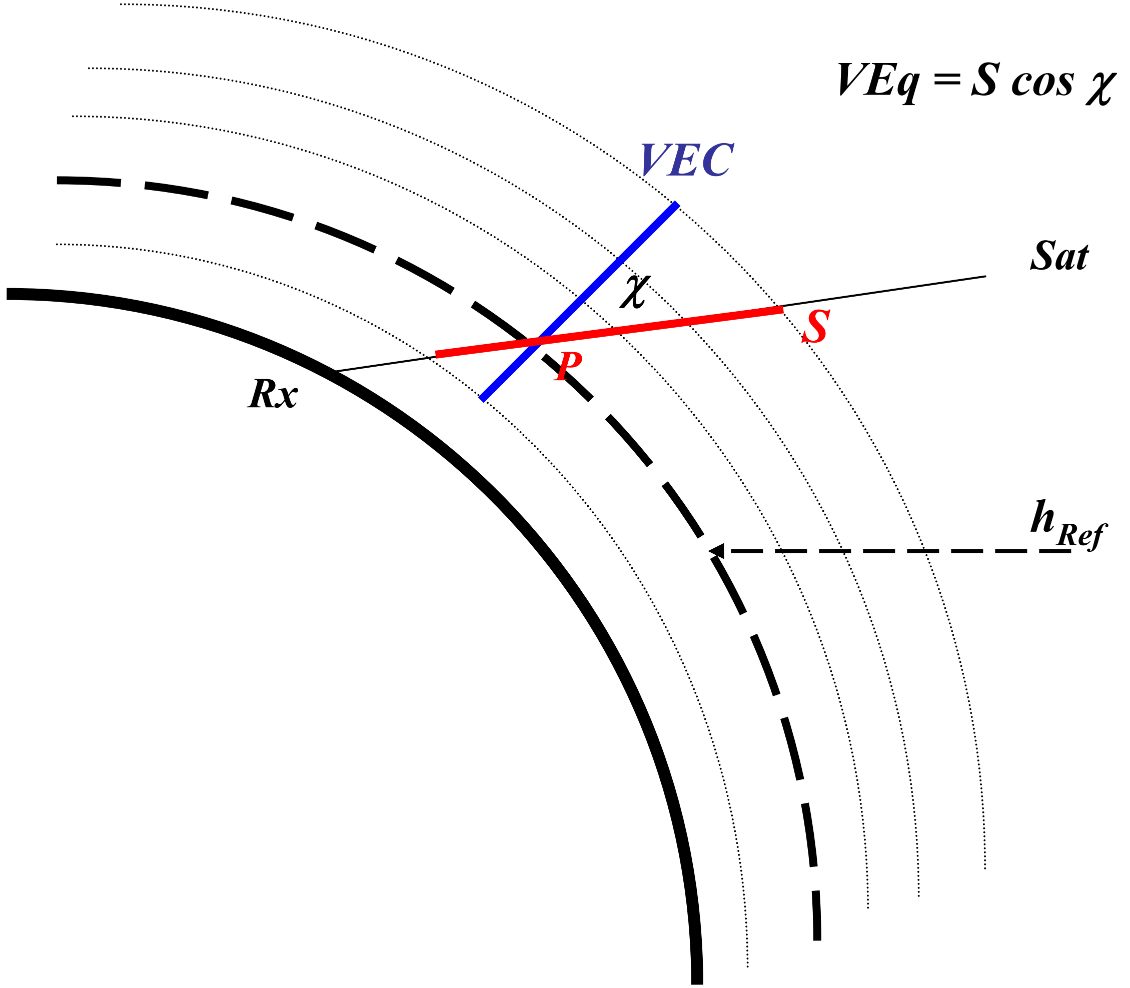
Plot ***VEC, VEq***

Plasmasphere can be included too using a suitable model

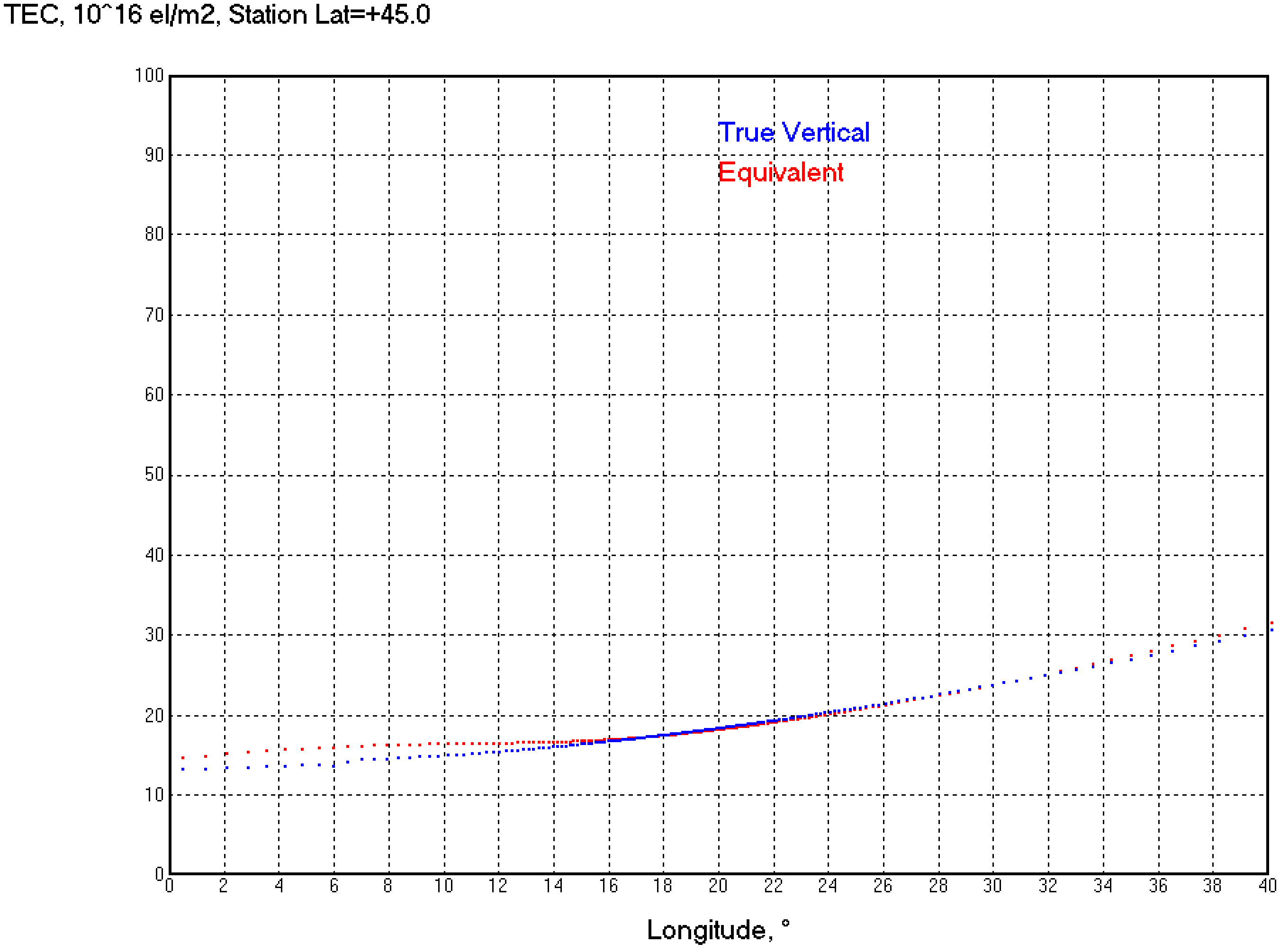
Integration paths for

S

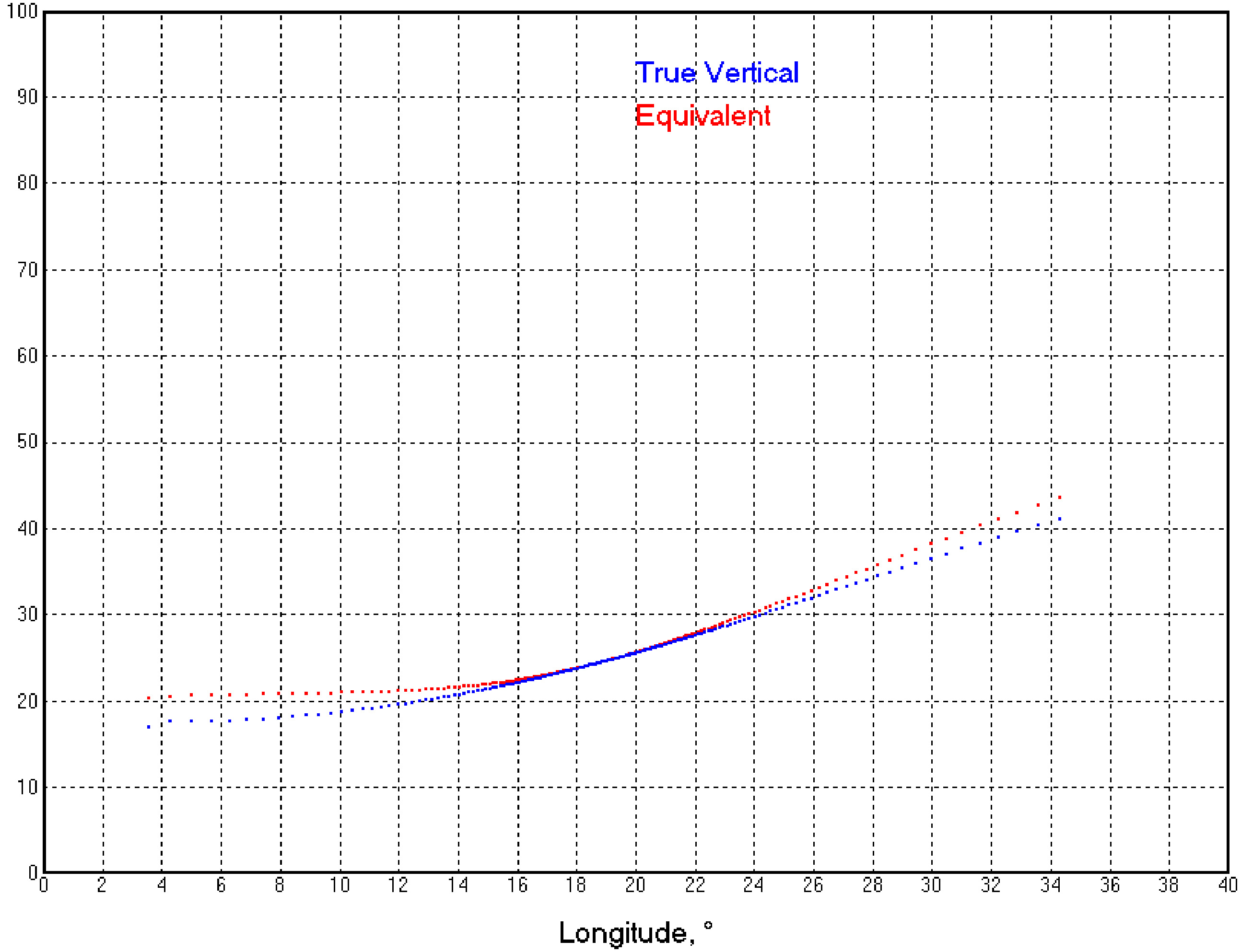
VEC

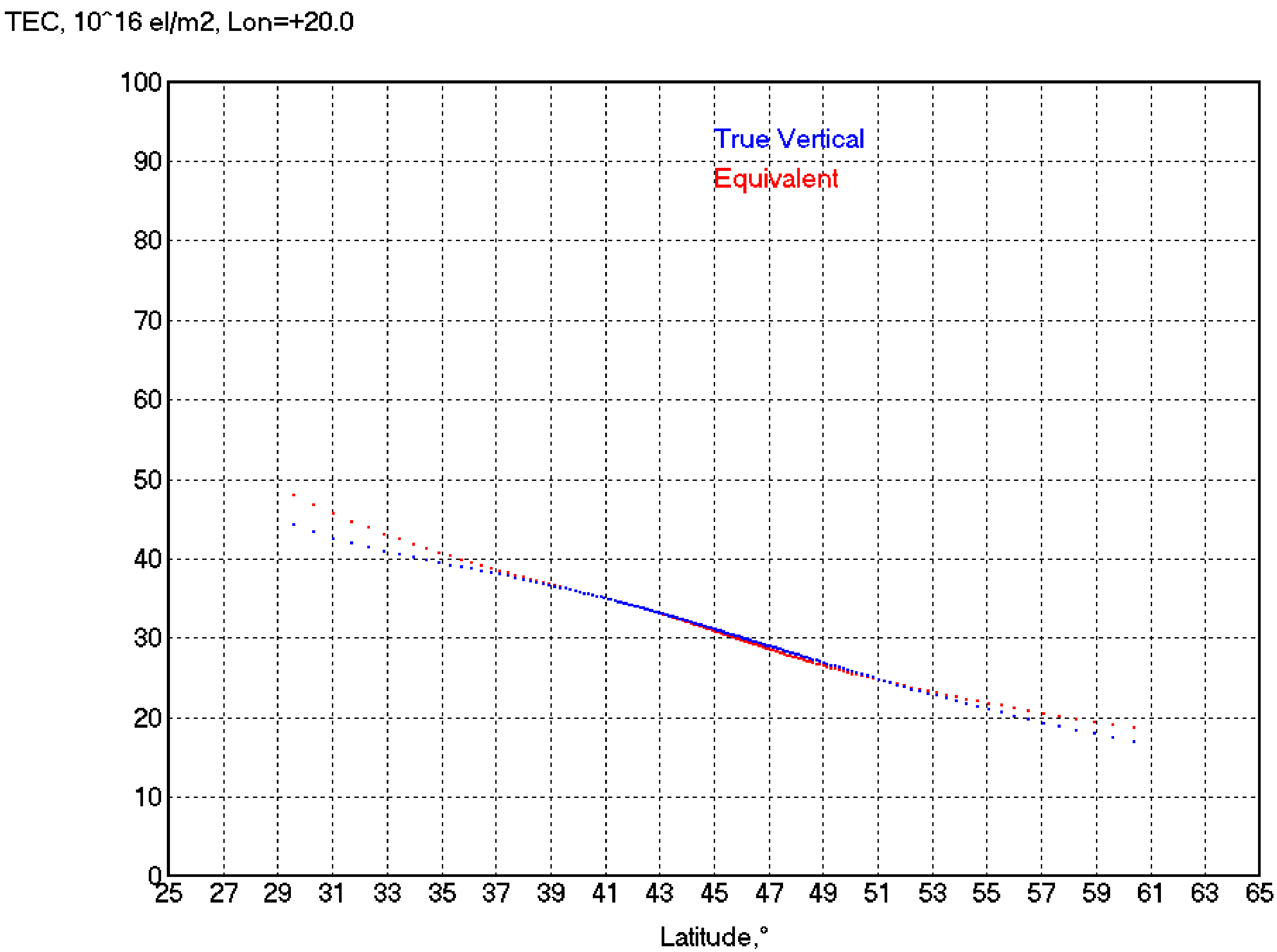


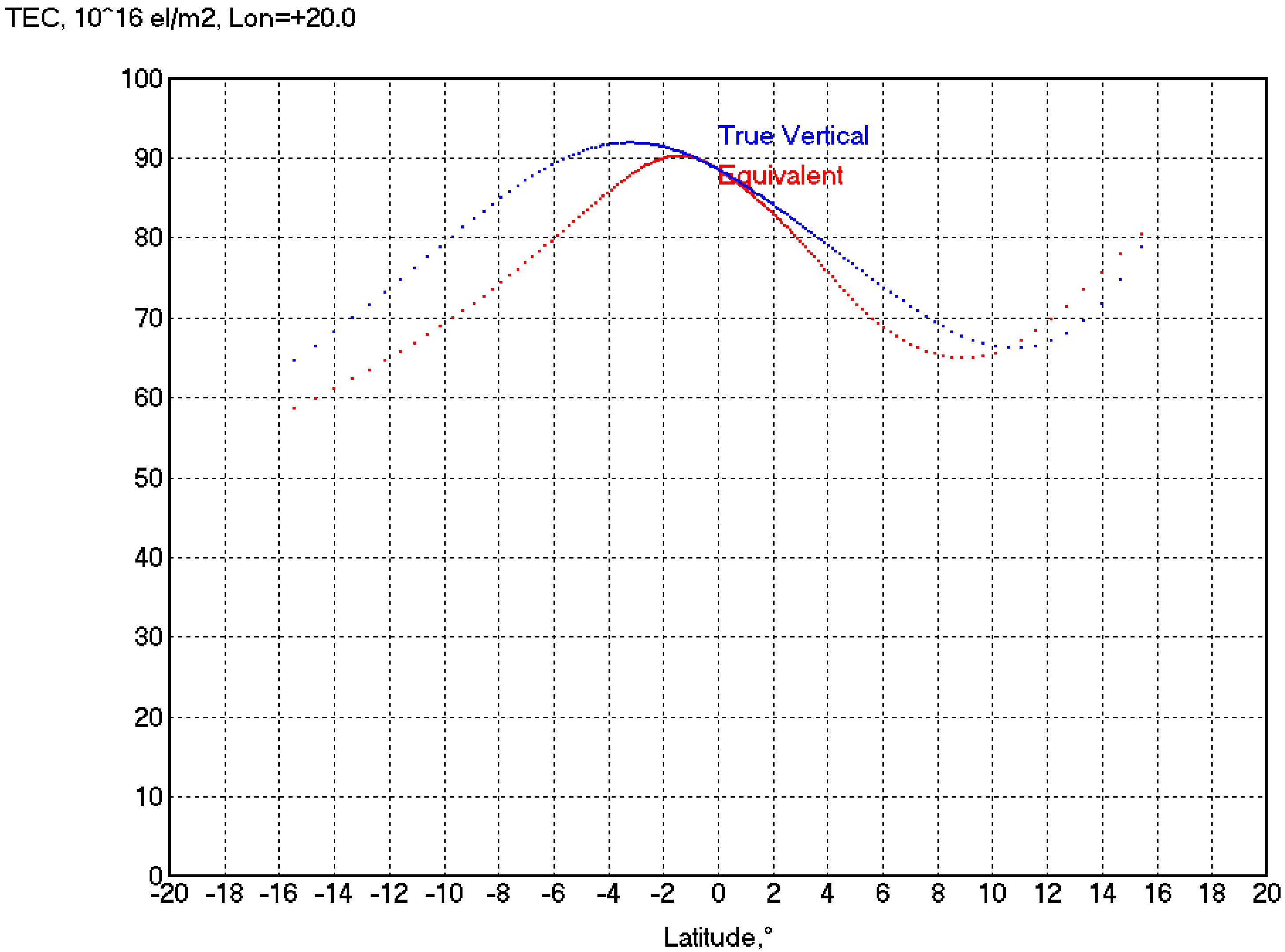
Simple uses of artificial data: How much ***VEC*** and ***VEq*** differ?



TEC, 10^16 el/m2, Station Lat=+00.0




TEC, 10^16 el/m2, Lon=+20.0
100
90
80
70
60
50
40
30
20
10
0
25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65
Latitude,°
True Vertical
Equivalent



TEC, 10^16 el/m2, Lon=+20.0
100
90
80
70
60
50
40
30
20
10
0
-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20
True Vertical
Equivalent
Latitude,°

Test of Single-Station, Arc-Offset solution

Generation of artificial truth data

Given all slants actually observed and archived

in a (quasi) complete set of IGS stations (≈ 200 per day)
for year 2000
for days 88-91 (March 28-31)

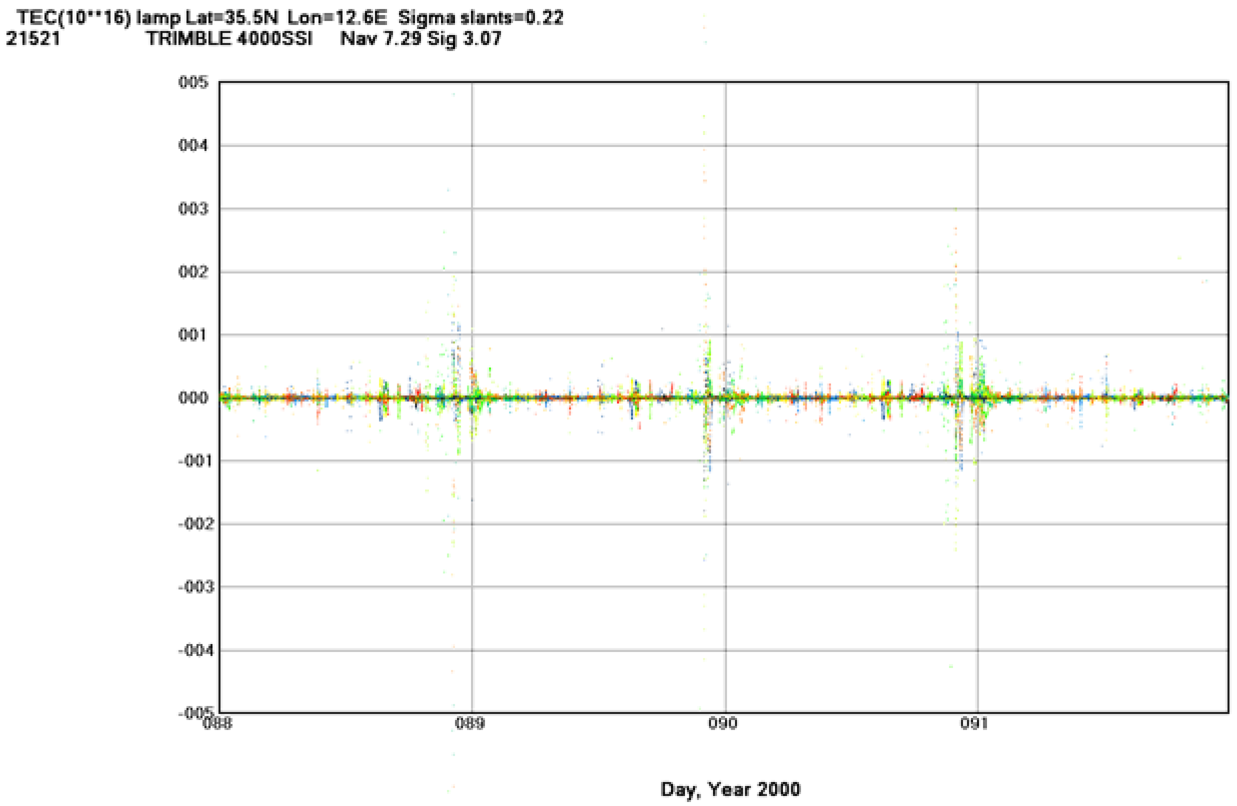
Re-compute them using
NeQuick (Az =150), integrating up to 2000 km

Therefore:

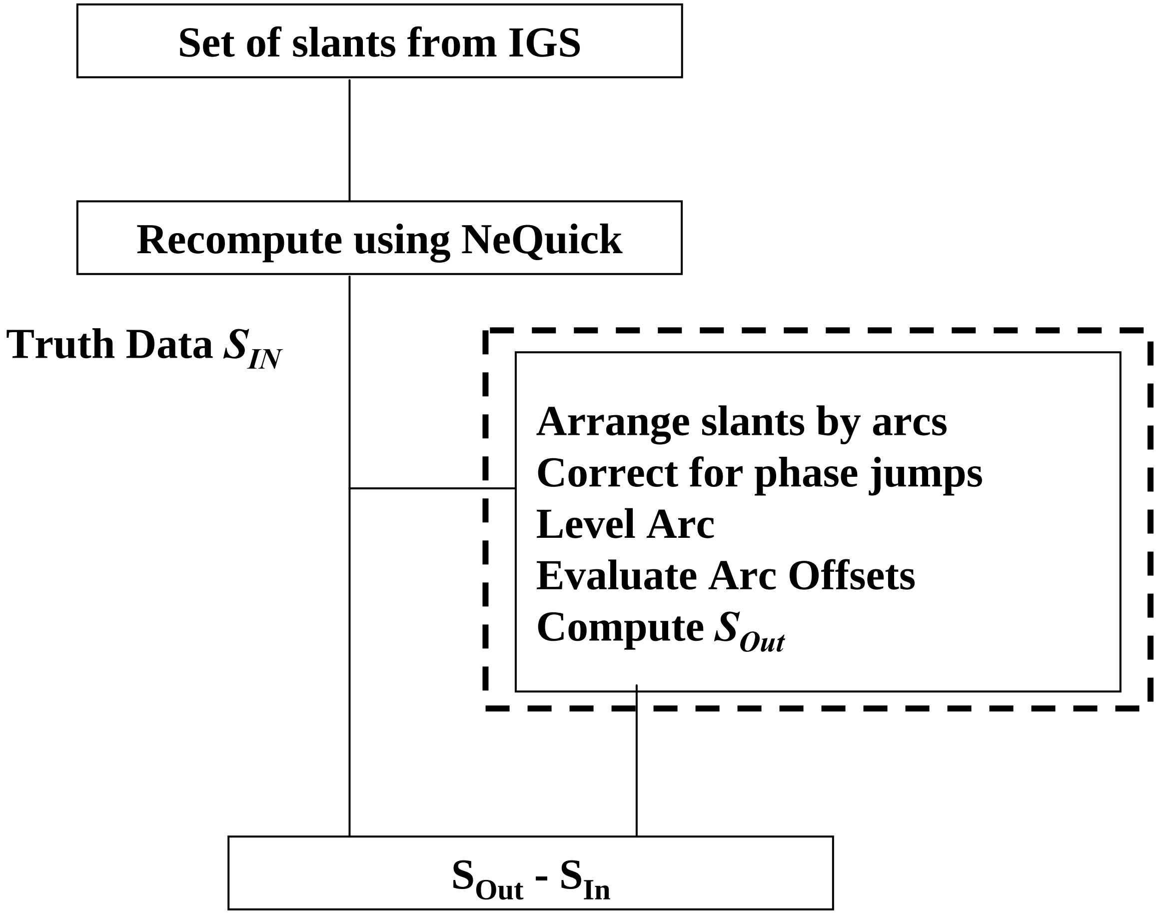
Not only the actual GPS constellation has been preserved for the reference period, but also the possible lack of observations (this will affect the solution)

Internal consistency: Residuals, simulated data

$$Res_{ijt} = S_{ijt} - \Sigma_n c^t_n p_n(l_{ijt}, f_{ijt}) \sec \chi_{ijt} - \Omega_{Arc}$$



Testing the calibration procedure



$\boldsymbol{S_{Out} - S_{In}}$ are plotted vs time

Worth (but expected) noting that errors at low latitudes are larger

Remark about highlighted arc:

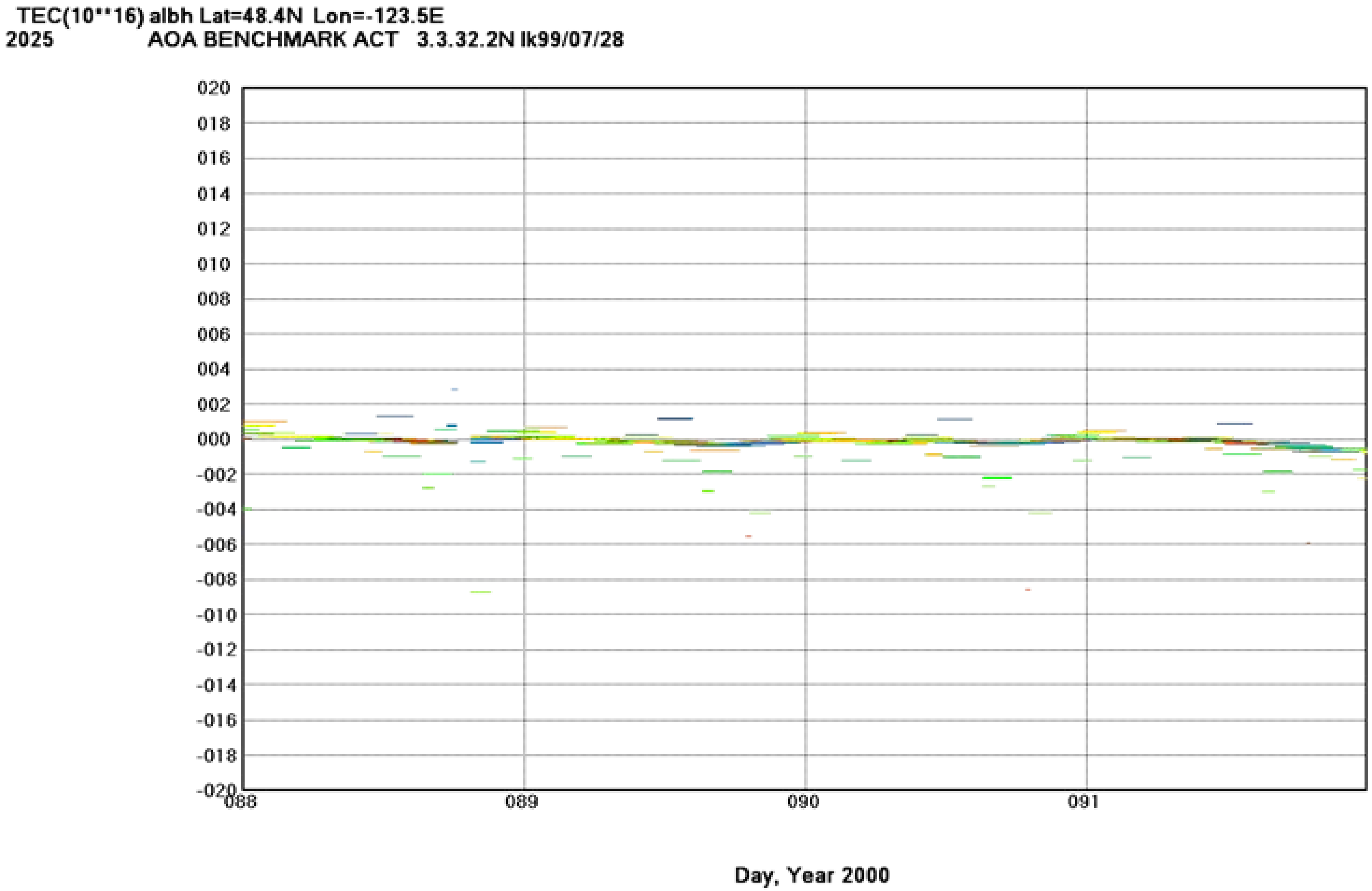
errors show a weakness of the solution**.**

These errors occur for arcs of low elevation also if, in some case, of long duration.

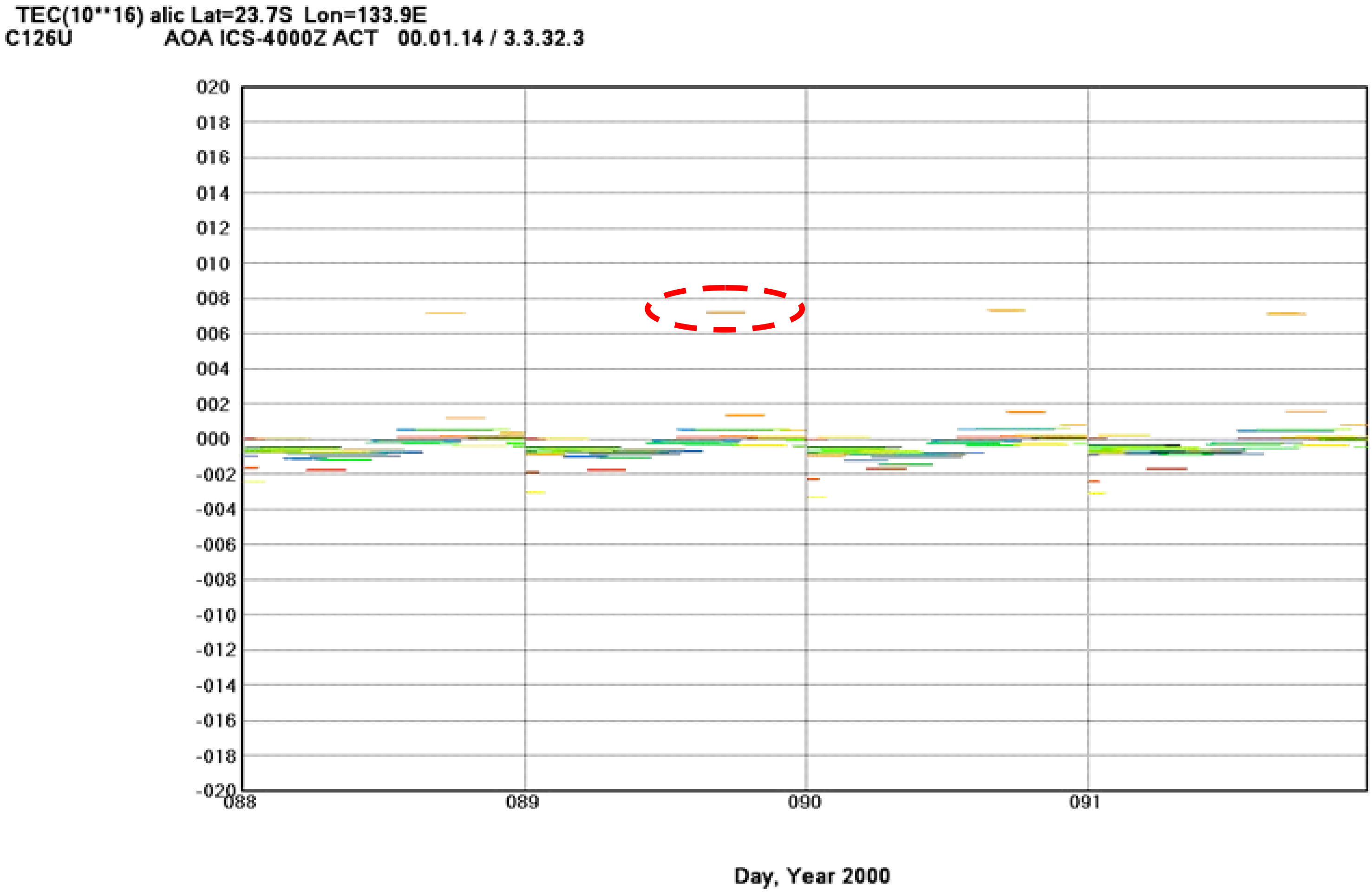
Processing real data, there is no chance to know if the subject arc is ill-calibrated (unless in presence of very strong errors)

Testing the solution with simulated data will (likely) enable to find a more effective way of avoiding such errors, or in a last instance, rejecting them

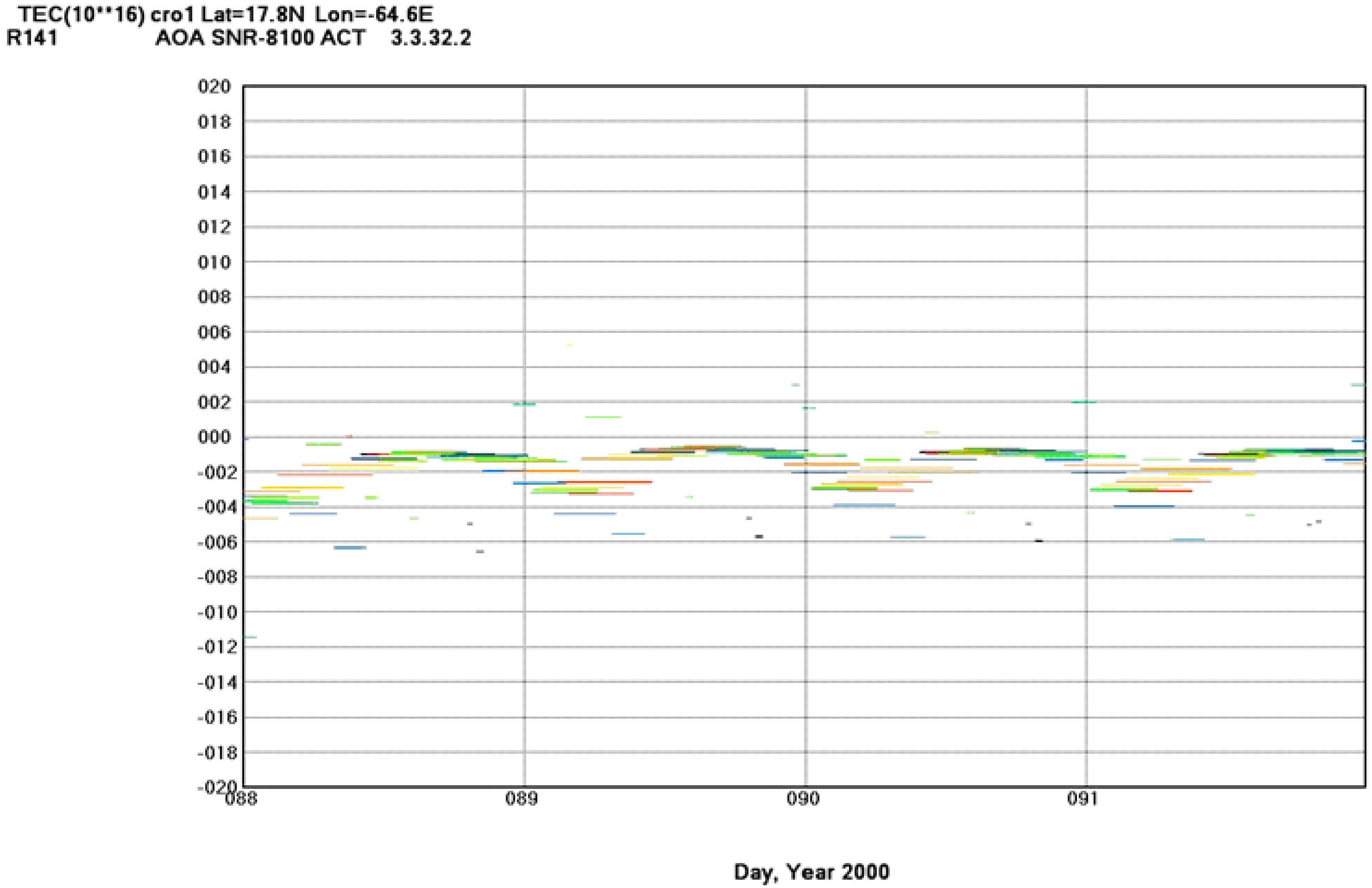
Slant$_{Out}$-Slant$_{In}$, TECu



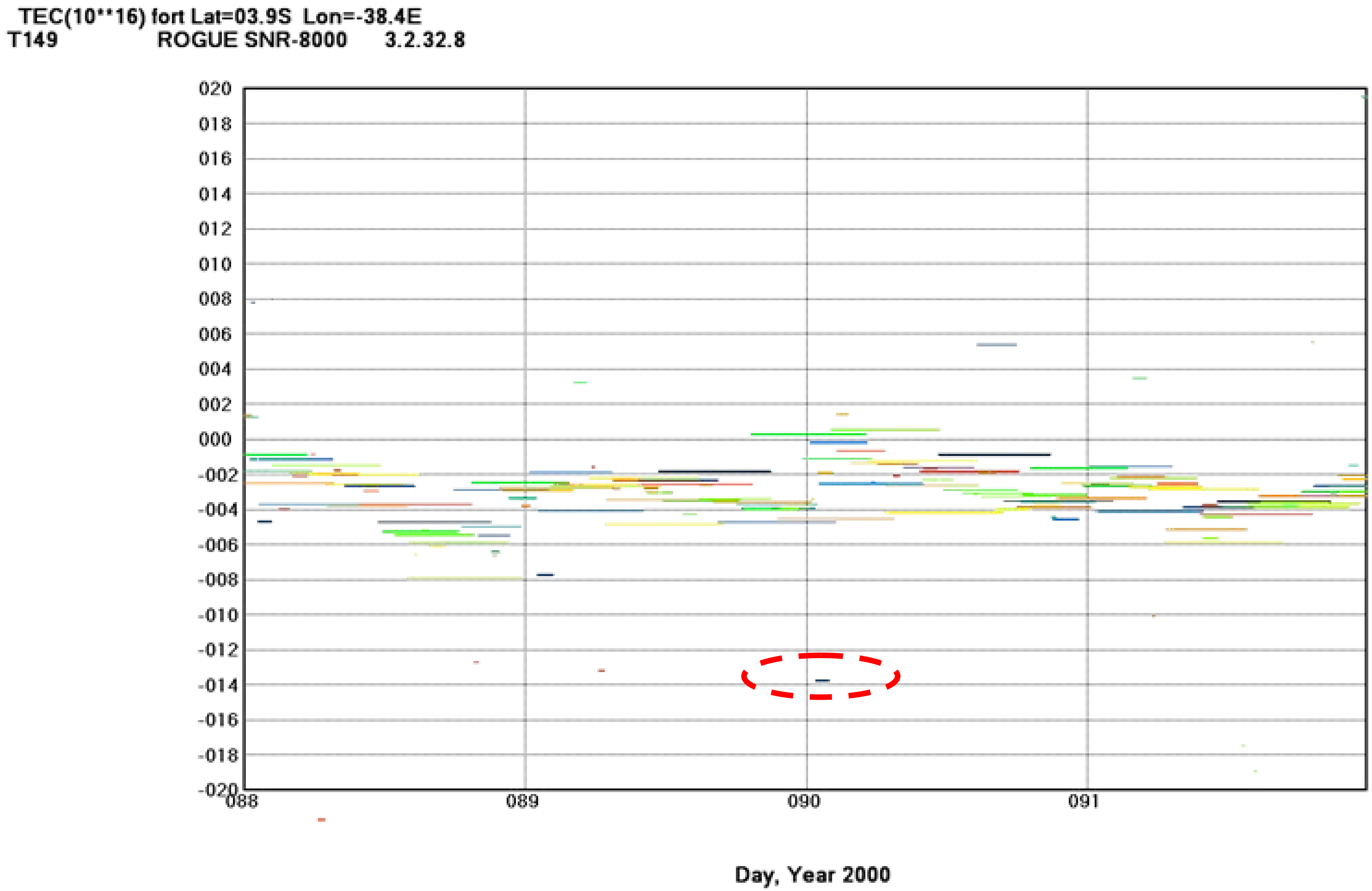
$Slant_{Out}$-$Slant_{In}$, TECu



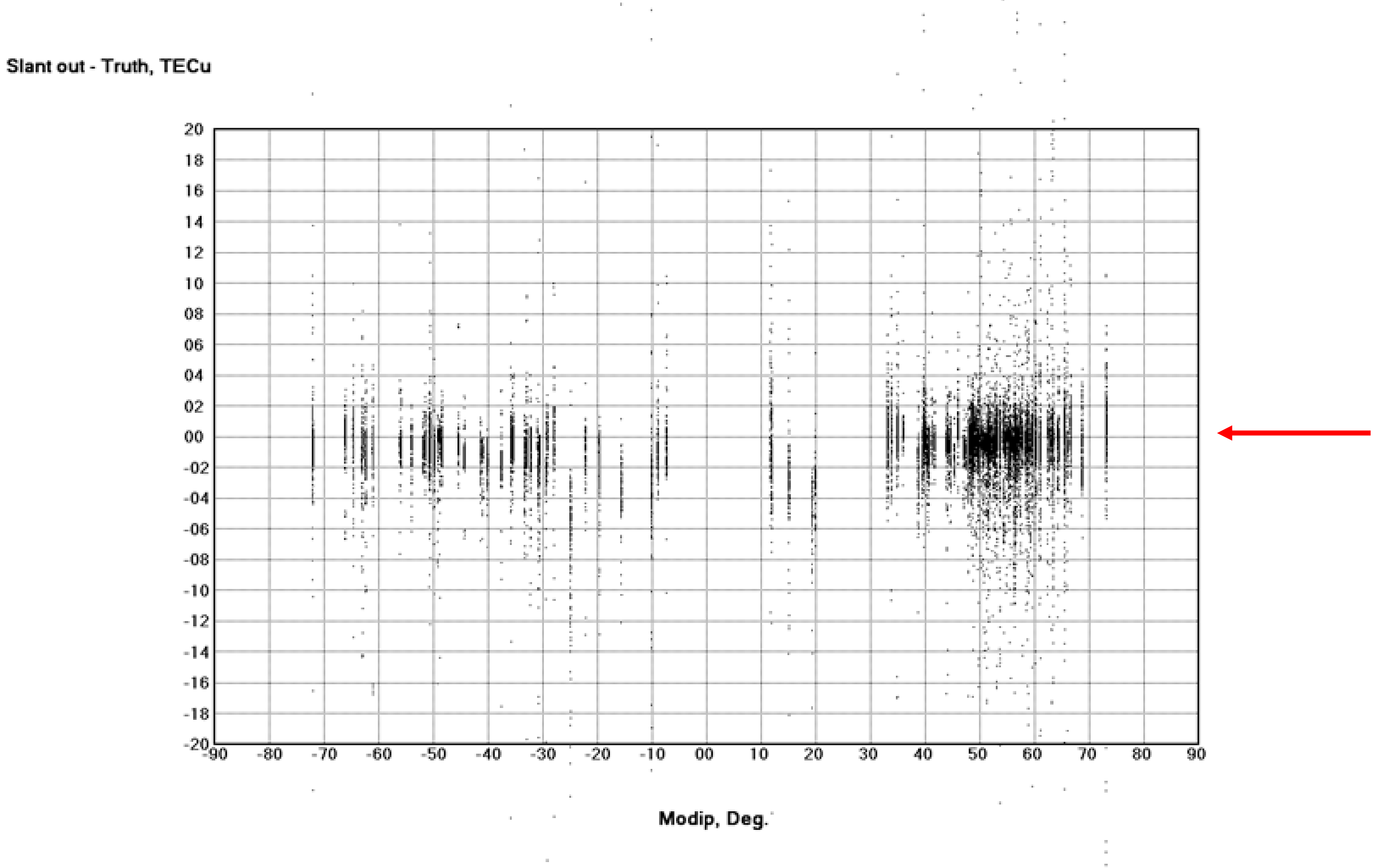
Slant$_{Out}$-Slant$_{In}$, TECu



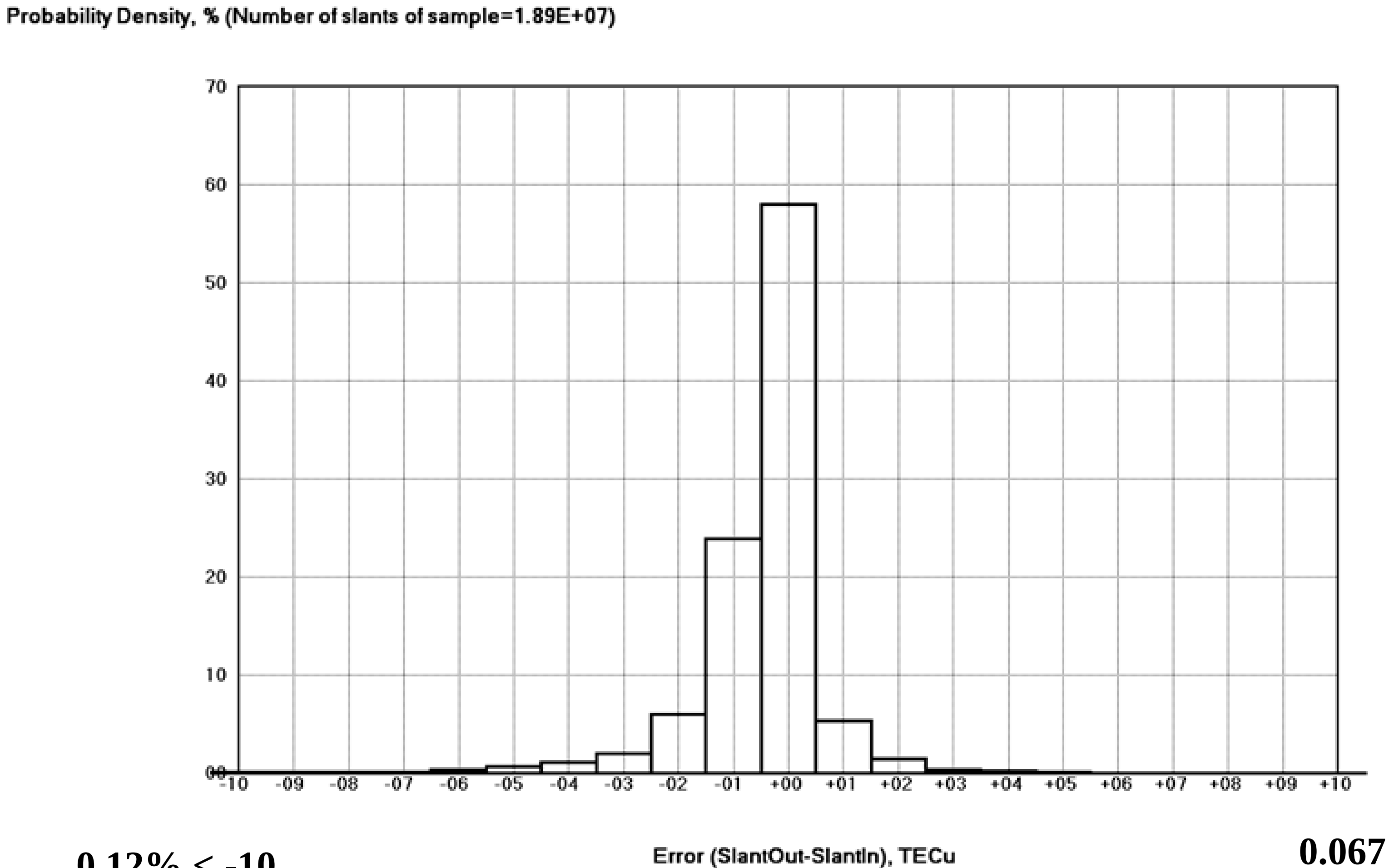
Slant$_{Out}$-Slant$_{In}$, TECu



An overall look to the errors: $S_{Out} - S_{In}$, whole set



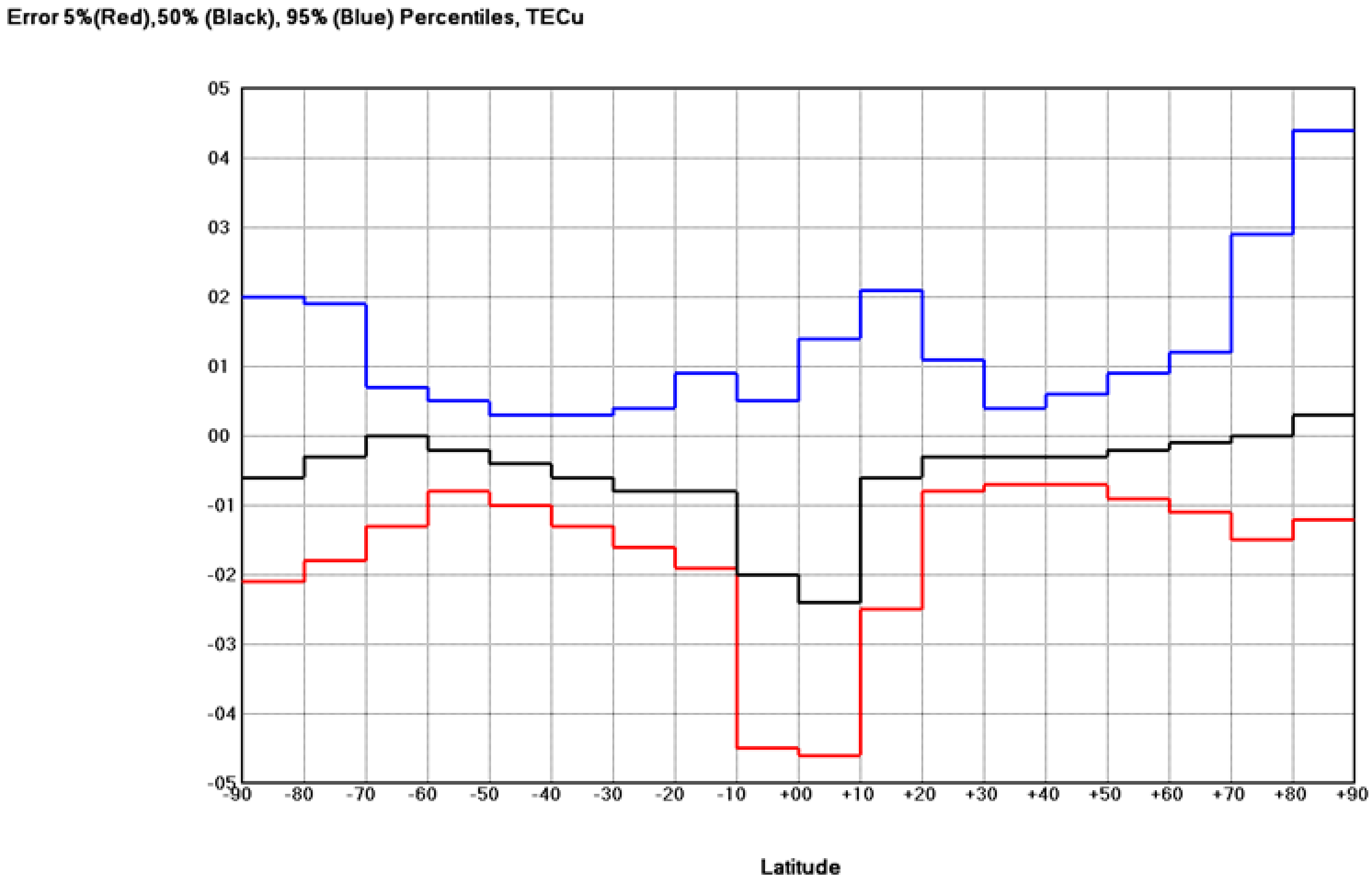
An overall look to the errors: $S_{Out} - S_{In}$, probability density



0.12% < -10

0.067 % > 10

Error's behavior vs latitude: percentiles, whole set



Simulation: role of multi-path contribution λ

An arbitrary set of ***satellite + receiver biases + multipath*** errors is added to model slants

Station bias γ = 25

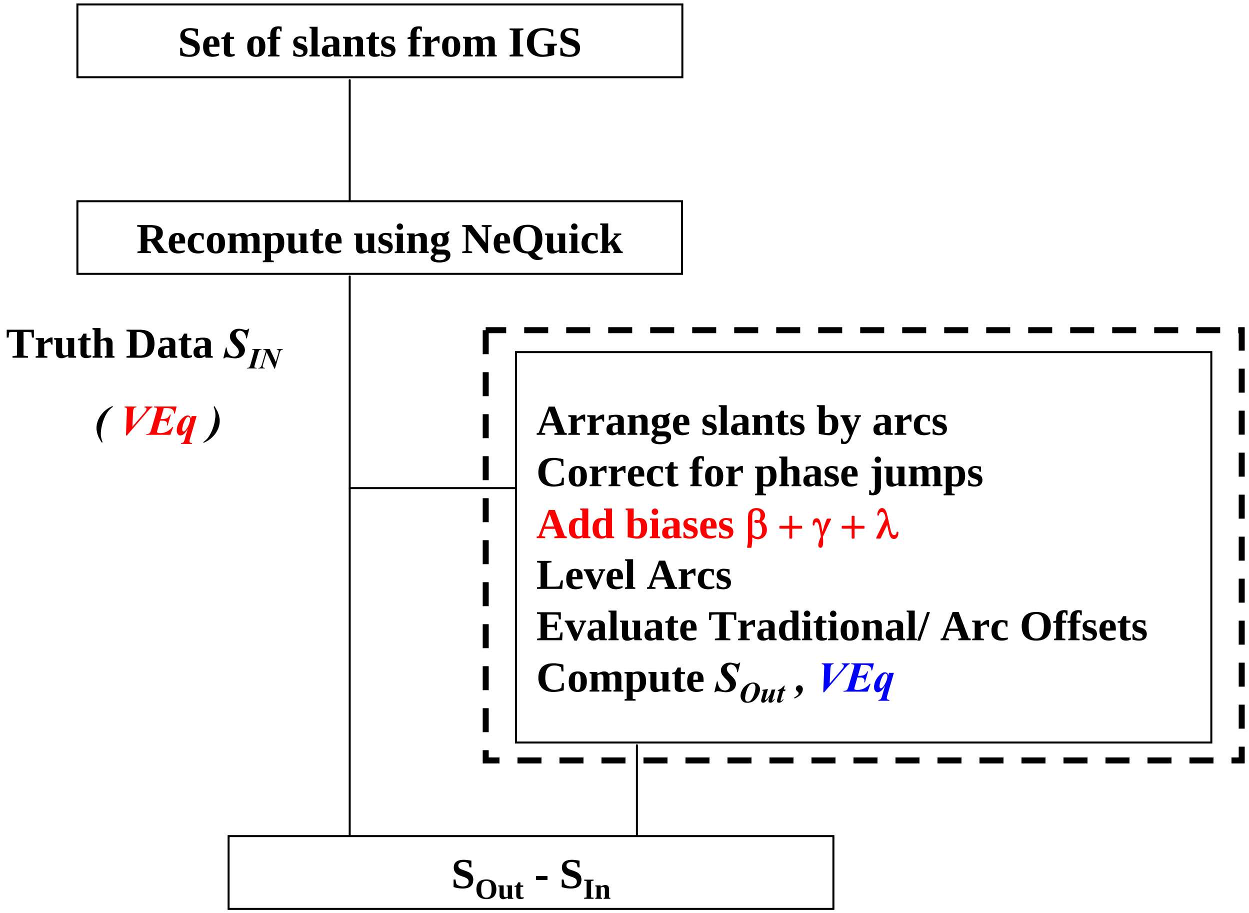
Satellite biases $\beta_i = 10 * (Rnd() - Rnd())\ , i=1,..,32$

LevelingError $\lambda_{Arc} = 10 * Rnd()$

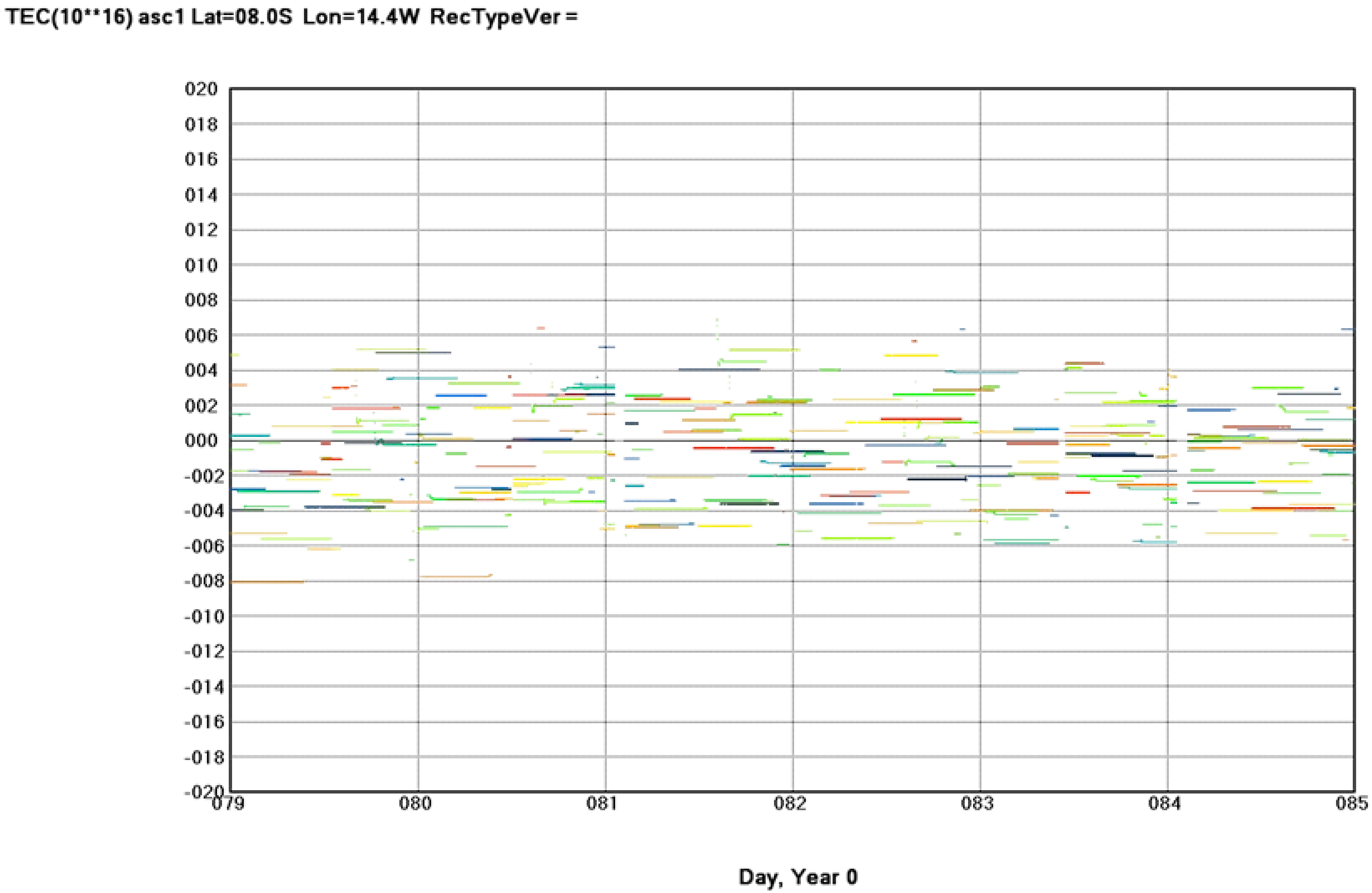
Arc Offset $\Omega_{Arc} = 1000 * Rnd()$

(both of the above for) ***Arc =1.. Number of Arcs***

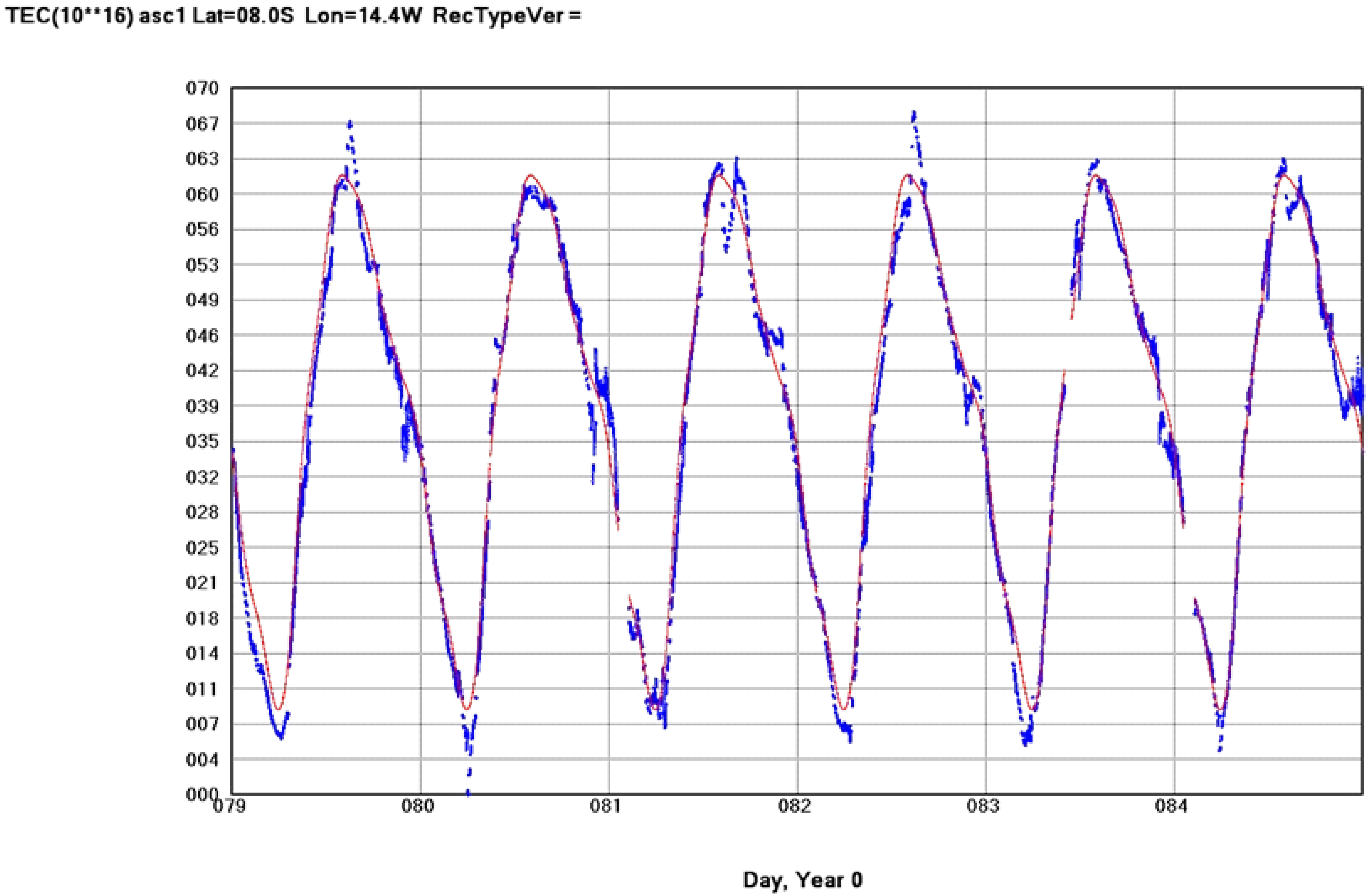
NextData are processed both by traditional and arc offset single-station calibration.


Set of slants from IGS
Recompute using NeQuick
Truth Data S_{IN}
(*VEq*)
Arrange slants by arcs
Correct for phase jumps
Add biases $\beta + \gamma + \lambda$
Level Arcs
Evaluate Traditional/ Arc Offsets
Compute S_{Out} , *VEq*
S_{Out} - S_{In}

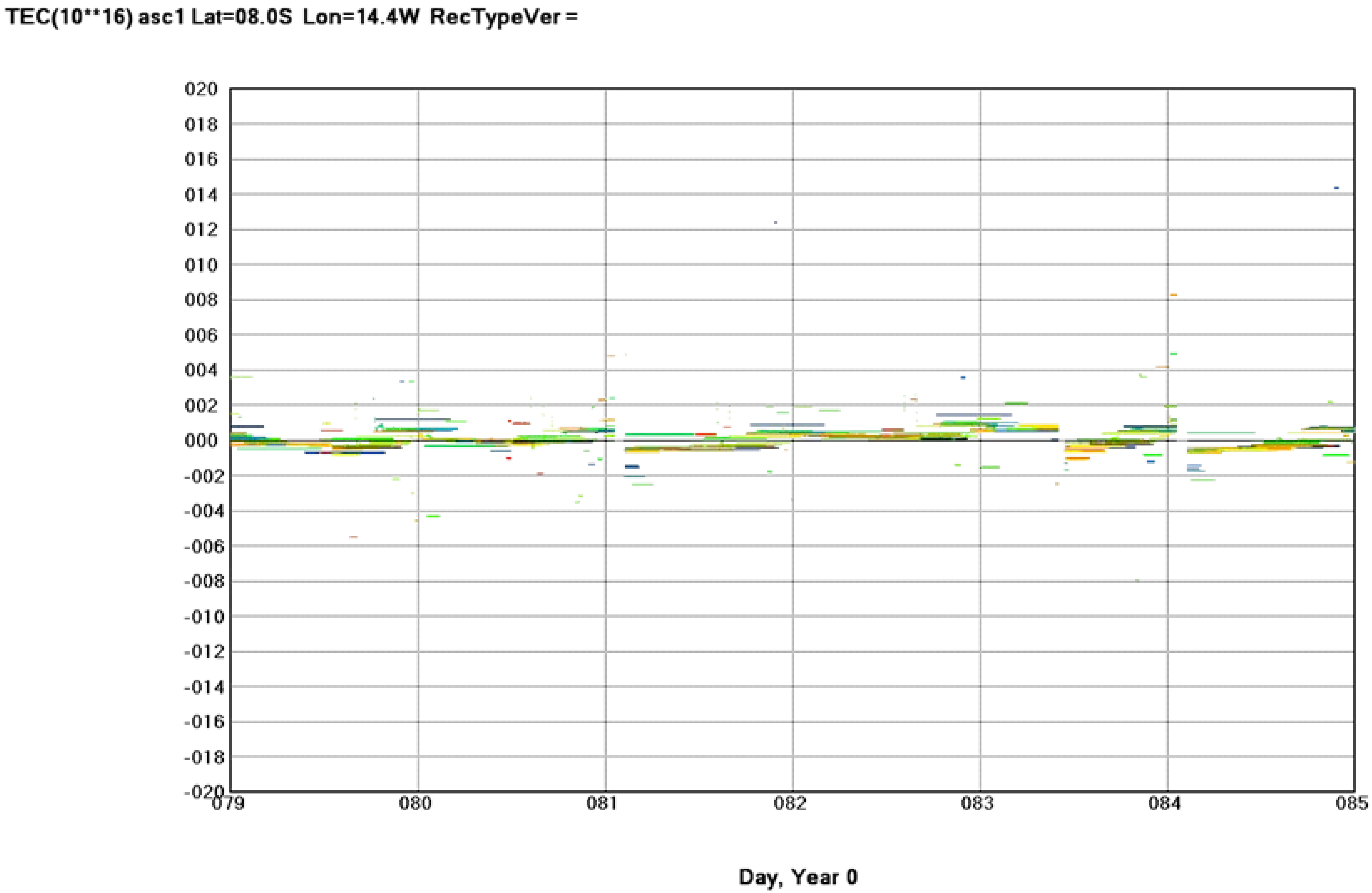
Traditional, $S_{Out} - S_{In}$



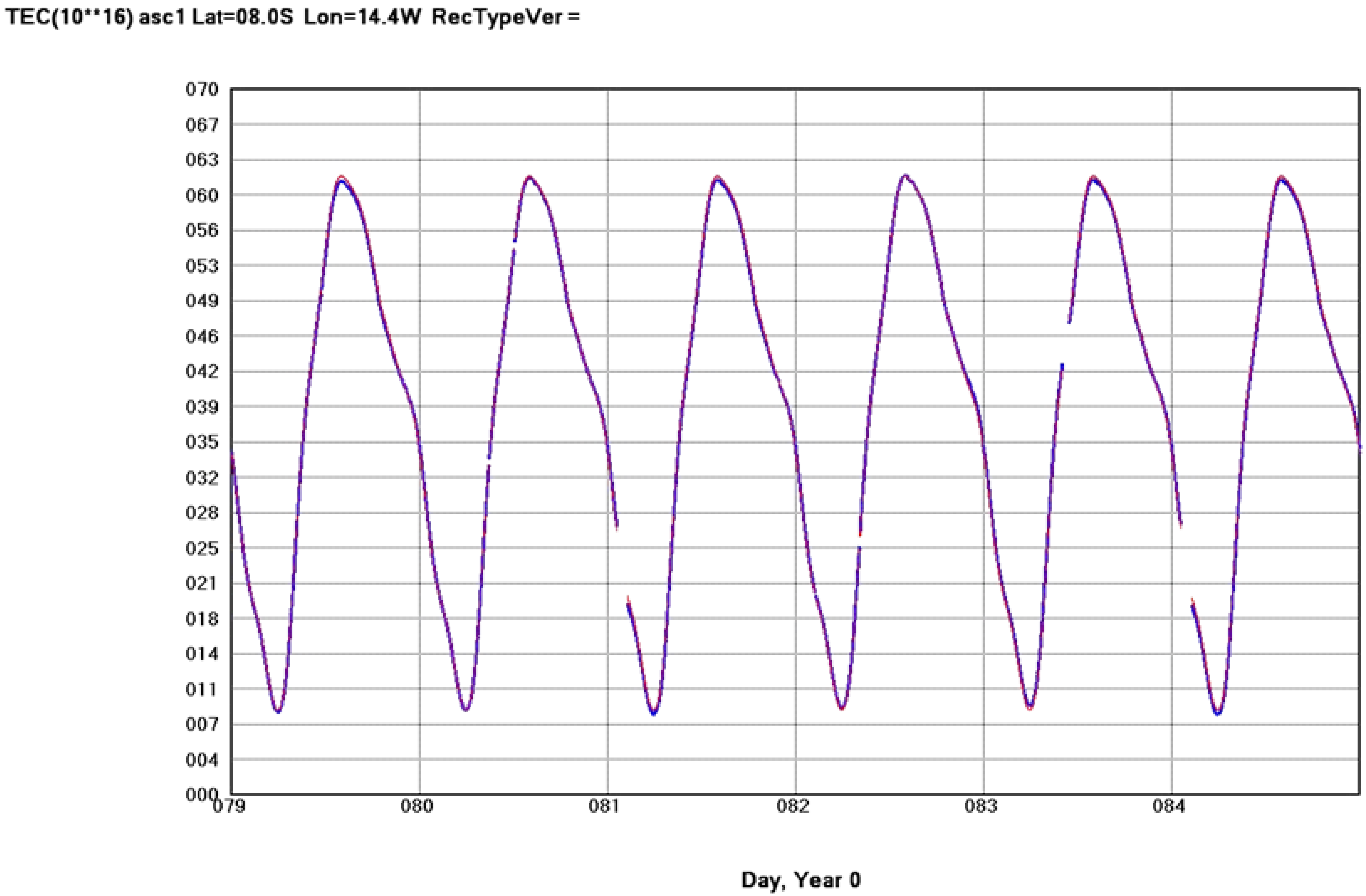
Traditional, *VEq* computed / *VEq* True



Arc Offset, SOut - SIn



Arc Offset, *VEq* computed / *VEq* True



Thank you